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Identification of reservoir facies & it's connectivity in heterogeneous reservoir through geostatistical techniques to reduce uncertainty: An integrated approach using in-depth petrophysical analysis & sedimentological core studies

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Abstract:

Identification of the facies and its distribution in 3D reservoir model has always been a challenging task in heterogenous reservoirs due to its complex lithology. To address this problem, prior delineation of different facies requires in-depth petrophysical analysis. Once the identification has been ascertained in the well locations their mapping and connectivity in 3D space is needed. The facies is defined as numerical values, therefore, data analysis in the geological context and its spatial relationship become essential to reach some logical conclusion. An integrated approach was adopted, where log, seismic data interpretation and geological information are translated into reservoir description.

Geostatistics, is a branch of applied statistics which deals with the spatial relationship between data point in the Geological context, comprises of indispensable tools & techniques for reservoir description. This also provides logical numerical models close to realistic behaviour of the strata in sedimentary process thus reducing the uncertainity in field development and planning. A scientific approach for collecting, organising, summarizing, presenting and analysing the data and drawing valid conclusion for reasonable decision based on analysis.

This study demonstrates methodology and work flow through a judicious combination of precise petrophysical analysis and geostatistical tools leading to reservoir property population in 3D space for robust Geo Cellular Model for better field development and hydrocarbon exploitation from this brown field.

Introduction

The challenge in the case of an oil and gas field was to accurately locate the reservoir bodies. Distribution of Reservoir facies was mapped using a stochastic pixel based method along with facies guided innovative log correlation scheme, which cover an area of about 4 Sq. Km. everywhere to ensure maximum similarity in the facies code.

Stochastic facies distribution is a widely used technique in reservoir modelling. For the present study, a facies indicator methodology has been used based on the Sequential Indicator Simulation principle. Facies Indicators is a stochastic pixel-based facies modelling technique that generates a discrete 3D facies parameter for the current realization. Each cell is assigned a facies code defining the facies that is present in that cell, based on probabilities calculated from well data and user-defined input.

Present study deals with identification of reservoir facies and their connectivity in heterogeneous reservoirs pertaining to clastic regime of a giant onland oil and gas field of India. Reservoir facies have been identified through core studies, log responses, processed output and various crossplots. In-depth petrophysical analysis has been carried out based upon sedimentological, petro-physical core studies and production data. Once the facies are identified, their connectivity in 3D space has been ensured through a innovative correlation scheme to ensure maximum similarity in the facies code. This process will not only help to identify the same layer but also give a realistic variogram model for its population in the 3D space- a key feature of this technique. After the facies are populated, Effective Porosity (Φ), Water saturation (Sw) & Permeability (k) are assigned to the facies in the entire 3D volume.

Workflow

The different mineral components and their distribution of the rock fabrics are responsible for defining the facies type. These minerals are having their own impact upon the log responses, therefore the identification of mineral constituents become essential for facies identification. The facies connectivity and its population in 3D space can be best propagate using Geostastical tools. The following sequential workflow was designed in order to achieve the objective of the project.

1. Understanding of the Area

Kalol Field falls in the Ahmedabad-Mehsana tectonic block of Cambay Basin. It is located about 16Km north of Ahmedabad covering an area of around 450 sq. km. The field was discovered with drilling of well Kalol#01 in 1961which was put on production in 1964.There are 11 pay sands i.e. K-II to K-XII from top to bottom sequence occurring between depth of 1250 to 1550m. The trap mechanism is strati-structural in K-II to K-IV, K-V and K-XII pay sands whereas it is stratigraphic in nature in K-VI+VII to K-XI. The predominant natural drive mechanism in major reservoirs like K-VI+VII, K-IX+X and K-XII is depletion drive and is operating under pressure maintenance.

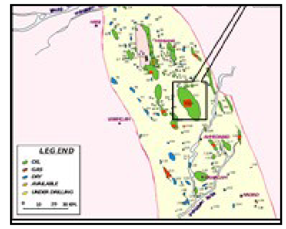


Fig-1: Location Map

2. Petrophysical core studies

Since the lithology is complex in nature therefore detail core studies has been done in few selected wells to ascertain the petrophysical parameters Archie (a, m, n), effective porosity, water saturation, permeability and grain density.Fig.2 shows the estimation of these parameters through core studies in three different wells. These parameters will be used in log processing for volumetric estimation of constituents minerals and fluid present in the pore space of the matrix.

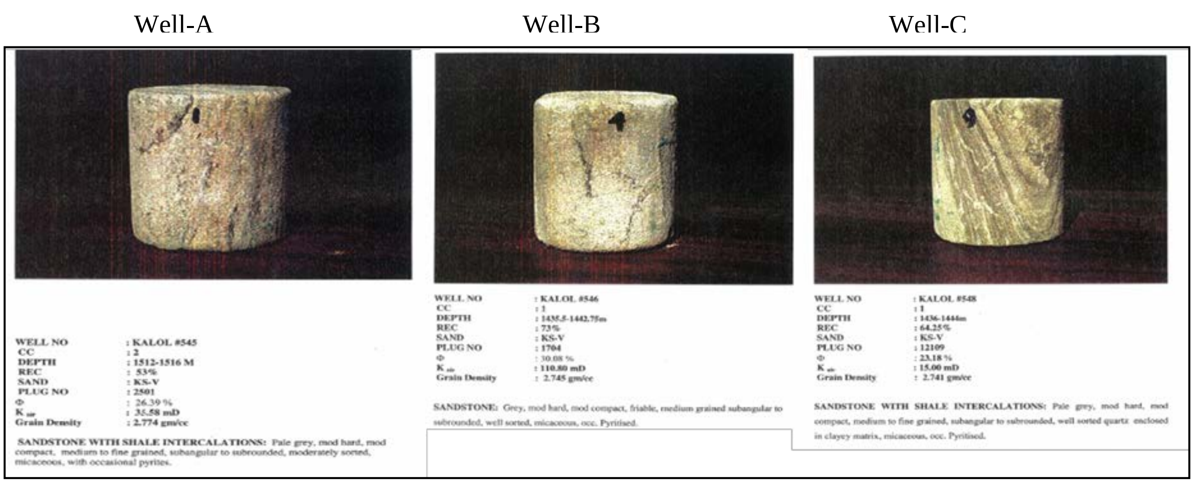


Fig-2: Core studies on the sample of three different wells

3. Sedementological studies

Rock is a mixture of minerals, responsible for petrophysical characteristics which are measured by logging tools. These properties are depends on:

- Individual characteristics of each of the constituent minerals forming the rock
- Relative percentages of each mineral, their distribution and bonding

Therefore the composition of the rock is required to be express in mineralogical terms. Sedimentological studies have been carried out in many core samples of various wells. Fig.3 shows the presence of heavy conductive/ non-conductive minerals and there relative weight percentage in the sample core.

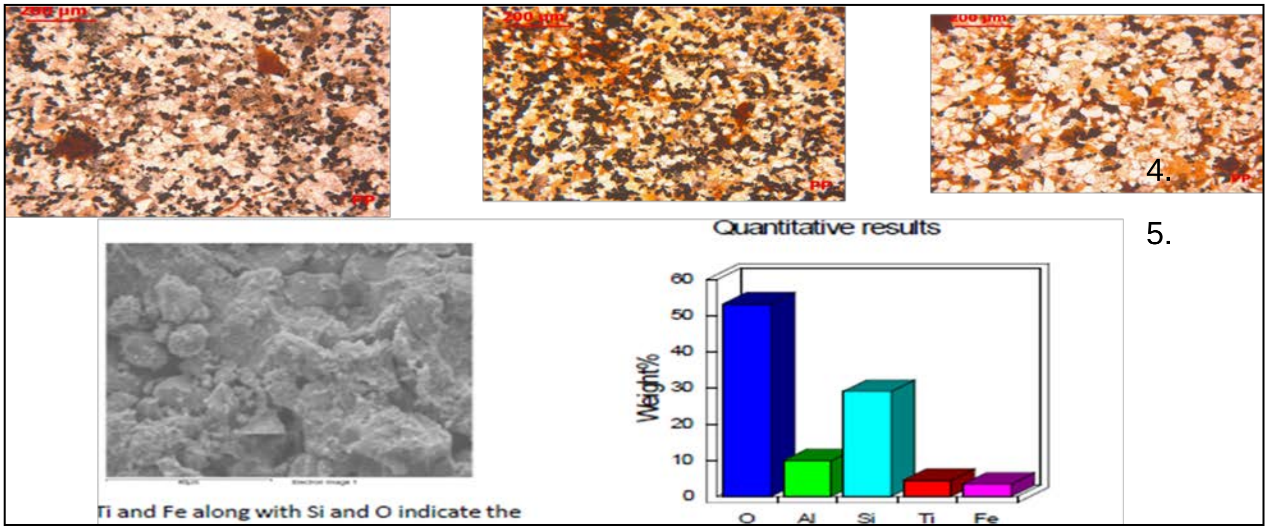


Fig-3: Sedimentological studies on core samples of three different wells

4. Log responses of the various tools

The different logging tool measurements are the responses of various kinds of lithologies which will allow an accurate and reliable objective for determination of geological attribute and petrophysical properties of rocks and more precisely of reservoir parameters. When the conductive minerals i.e., Fe, Ti, Illemenite, Pyrite, Haemetite and Limonite present in upper reservoir (above Kansari shale) having adverse effect on resistivity tools for lowering off the resistivity but Siderite present in shale (below Kansari shale) has increased the resistivity. Presence of radioactive mineral i.e. Allanite/Monanzite and Uranium rich organic matter has increased the value of gamma-ray on the log responses. The effect of these minerals has to be removed in petrophysical analysis. Fig.4 shows the effect of different mineral on logs.

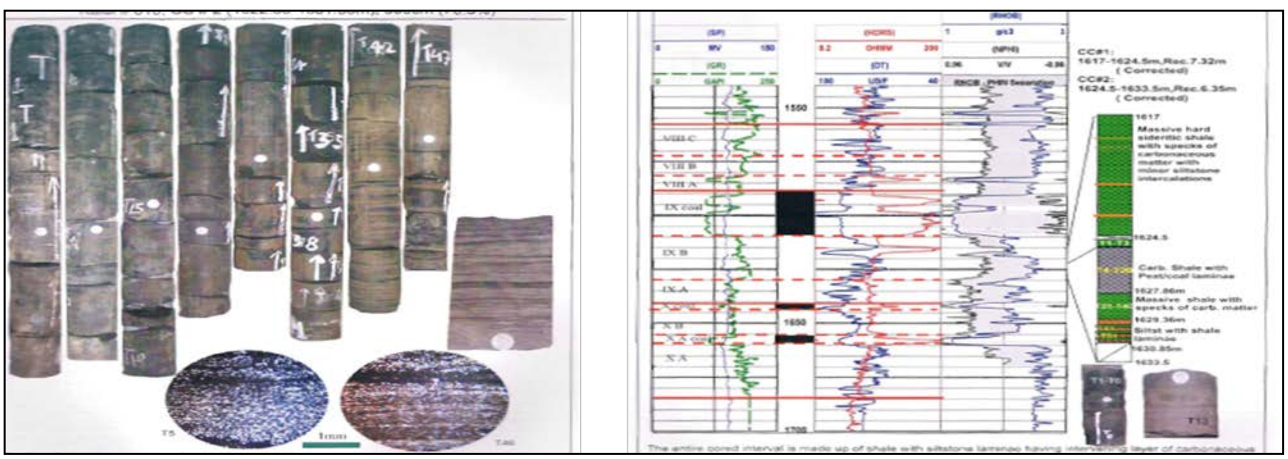


Fig-4: Effect of heavy conductive/non-conductive and radioactive minerals on logs

5. In-depth petrophysical Analysis

For determination of rock petrophysical properties an adequate logging suit is necessary which can measure the desire property accurately. Since the lithology is very complex in nature and a lot of heavy and conductive minerals are present, therefore fixing the petrophysical model become very important for right estimation of the petrophysical properties. Once the Petrophysical model has been fixed, it will be applied for estimation of the reservoir parameters i.e. Effective Porosity (Φ), Water saturation (Sw) and Volume of Clay (VCL) using multi-mineral least square optimization technique. From this technique the effect of conductive/nonconductive, heavy minerals, radioactive minerals and different clay contents has been taken in to account Fig 5A & 5B.

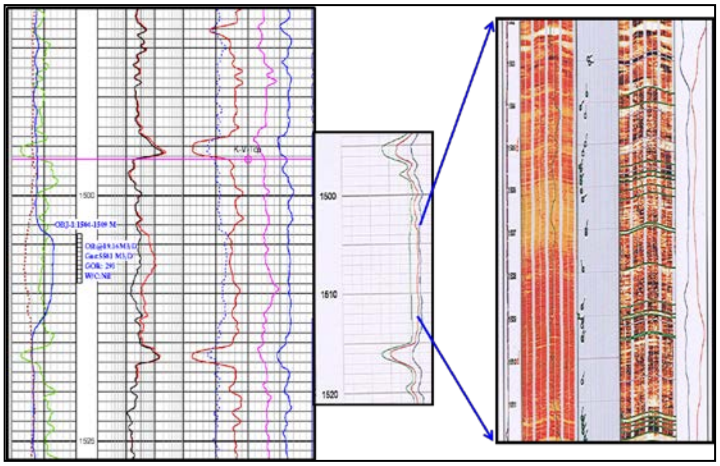


Fig-5A: Effect of conductive mineral on Image logs

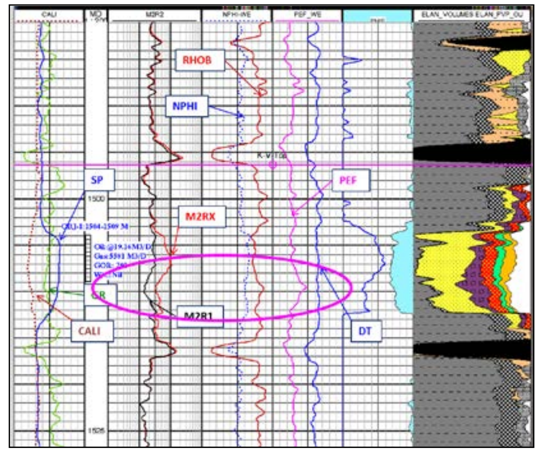
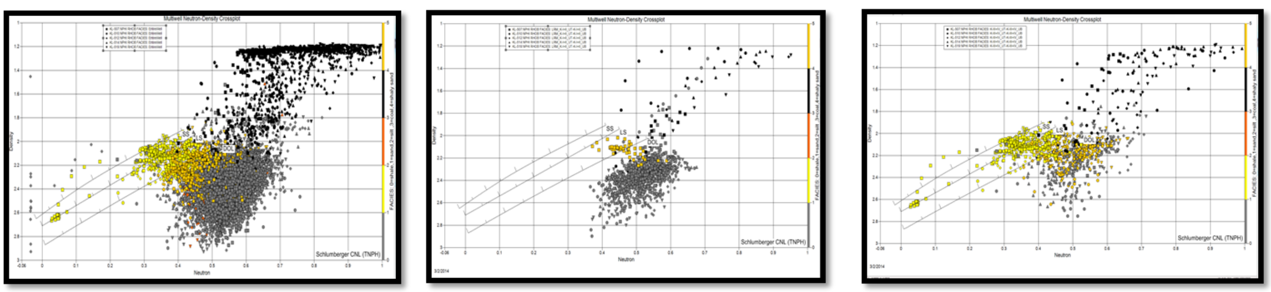
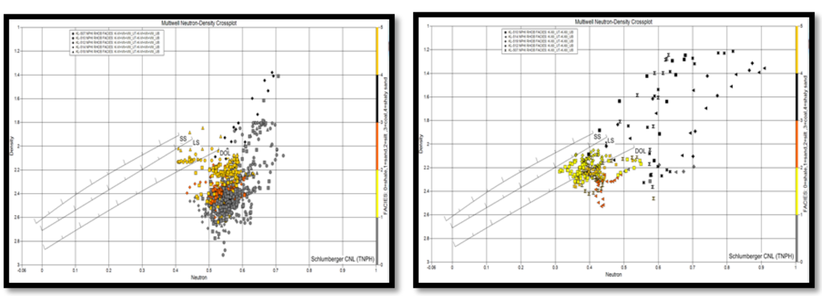


Fig-5B: Multi-mineral processing of logs

6. Cross plot technique for facies identification

Based on the processed output from log processing and log responses, various crossplots have been taken to understand the criteria for defining the various facies in the different reservoir. Fig.6 shows the crossplots of Neutron & Density which reveals a clear understanding of the criteria for facies demarcation of various litho-sequences.



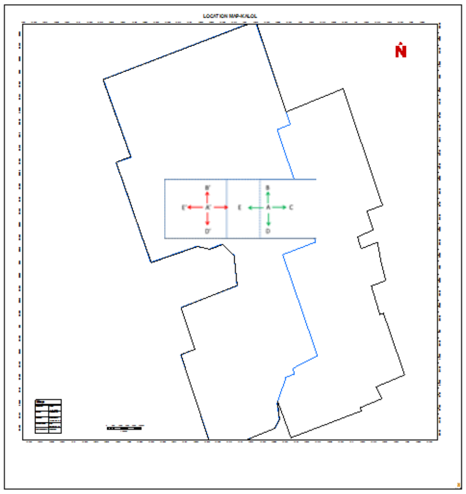


Facies	RHOB	NPHI
0-Shale	2.25 - 2.82	40 - 65
1-Sand	<2.2	20-40
2-Silt	>2.40	>45
3-Coal	<1.8	>45
Shaly Sand	2.2~2.40	30~45

Fig-6: Cross-plot technique for facies identification

7. Facies correlation scheme

After facies identification, their connectivity in 3D space has been ensured through an innovative correlation scheme by taking each well surrounded by at least one well in all direction (N, S, E & W) to ensure maximum similarity in the facies code. This scheme has been implemented in entire 3D volume of study. Fig. 7A shows correlation scheme which covers an area of 4 sq. km. at every well location, while Fig.7B shows the actual log correlation taking log and processed log data for generation of facies log for each well.



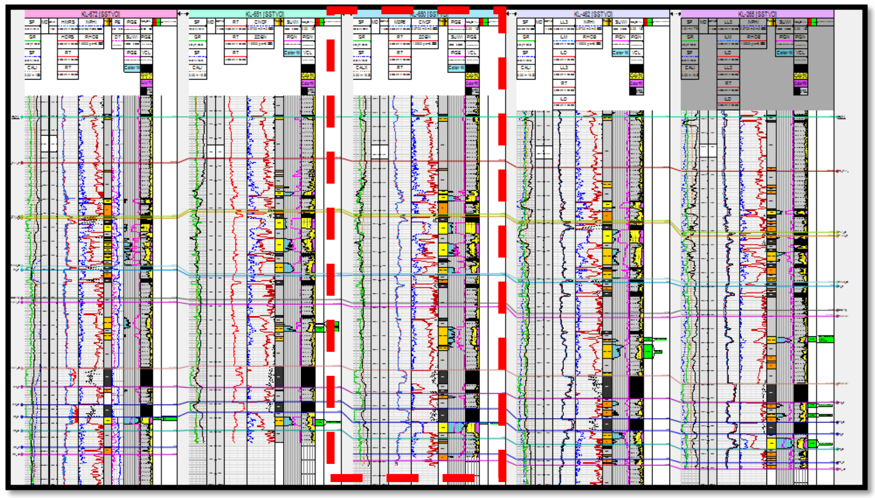


Fig-7A: Facies correlation

Fig-7A: Well log correlation and facies log creation

8. Variogram Analysis

Variation of the property in 3D space is a function of the separation distance between data points, therefore spatial statistics depends on the relative position of the data to each other. Variogram is a very strong quantitative descriptive tool which measures the variation of property amongst the data points in space. This tool is based on the principle that two points close together are more likely to have similar value than points far from each others. Intensive variogram analysis in vertical and horizontal directions for all facies have been done in all the zones keeping in view of the layering scheme, vertical and horizontal variability and direction of sediments etc. These variogram analysis have been used in population of different facies and petrophysical properties in the different zones. Fig.8 shows vertical variogram of different facies in the area of study.

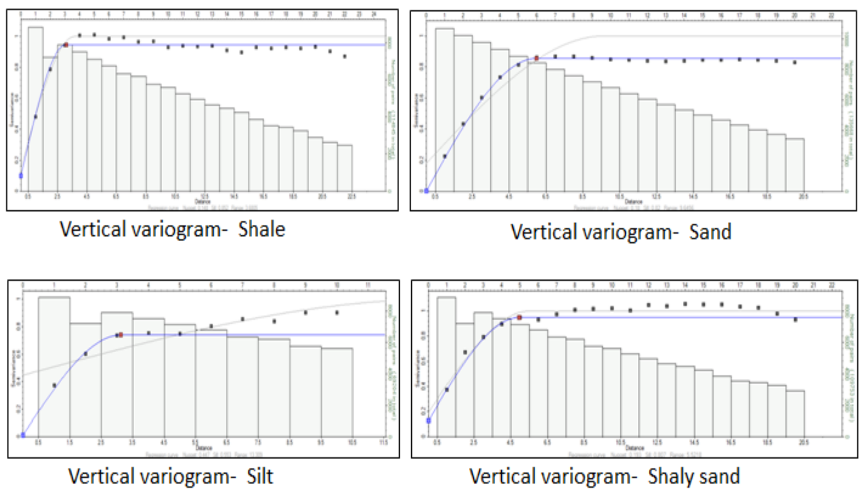


Fig-8: Variogram analysis in vertical direction

9. Facies Population & its connectivity using Geo-statistical approach

To depict the geological process both during and after deposition facies modeling play a vital role. It will not only describe the deposition pattern but also help to populate the right reservoir property in right place which accounts for optimal exploitation of the reservoir. To capture the reservoir architecture with flow unit and barriers a stochastic pixel based method based on Sequential Indicator Simulation trend has been adopted. This method will produce random facies in 3D space, which honors the up-scaled data with multiple realizations.

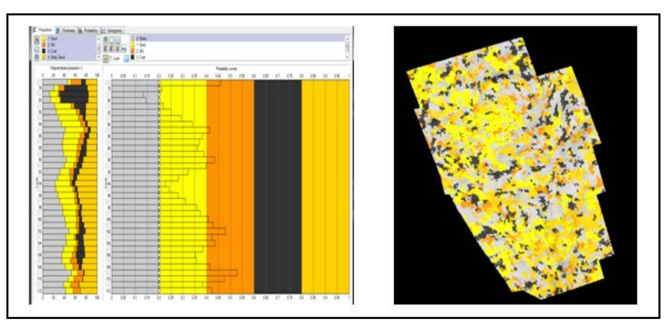


Fig-9A: Vertical proportional curve Fig-9B: Facies Modeling

Fig. 9A is a vertical proportion curve of all the facies, which will decide the relative proportional and probability function for population of different facies in different layers in vertical direction along with vertical variogram. Fig. 9B shows the population of all the facies in all the layers after facies modeling process.

10. Validation of the results

The facies model thus generated based on variogram analysis and vertical proportional curve has been calibrated at layer no 84 at the well location. Fig-10 A & B shows the populated facies is correlated with the upscaled facies log at well locations. This shows the right estimation of properties in the entire 3D volume. This facies model will be used in petrophysical modeling process.

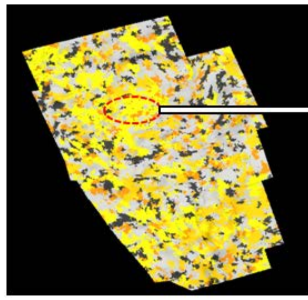


Fig-10A: Facies at layers no 84.

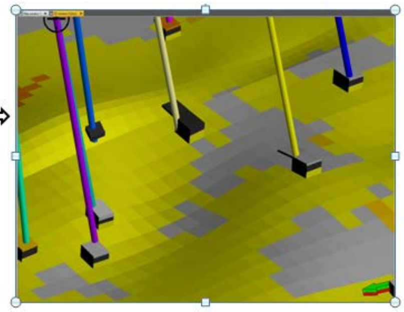


Fig-10B: Validation of facies at well location

Conclusions:

The present study has clearly brought out an approach for identification of litho-facies and its connectivity at reservoir level in a complex heterogeneous environment in judicial way using geo-statistical technique. The designed sequential workflow has not only given the lead for exploitation in unknown area but also reduced uncertainty for exploitation strategy and development planning. The industry proven geo-statistical tools which allow pixel based stochastic modeling has produces multiple equally probable realization for facies output, out of which the most likely results has been considered for property population and reserve estimation.

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